(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 027 911**
A1

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **80105914.8**

(22) Date of filing: **30.09.80**

(51) Int. Cl.³: **B 01 F 3/04**
// B01F7/24, C02F3/14, C12M1/04

(30) Priority: **02.10.79 US 81175**

(43) Date of publication of application: **06.05.81**
Bulletin 81/18

(84) Designated Contracting States: **DE FR GB IT**

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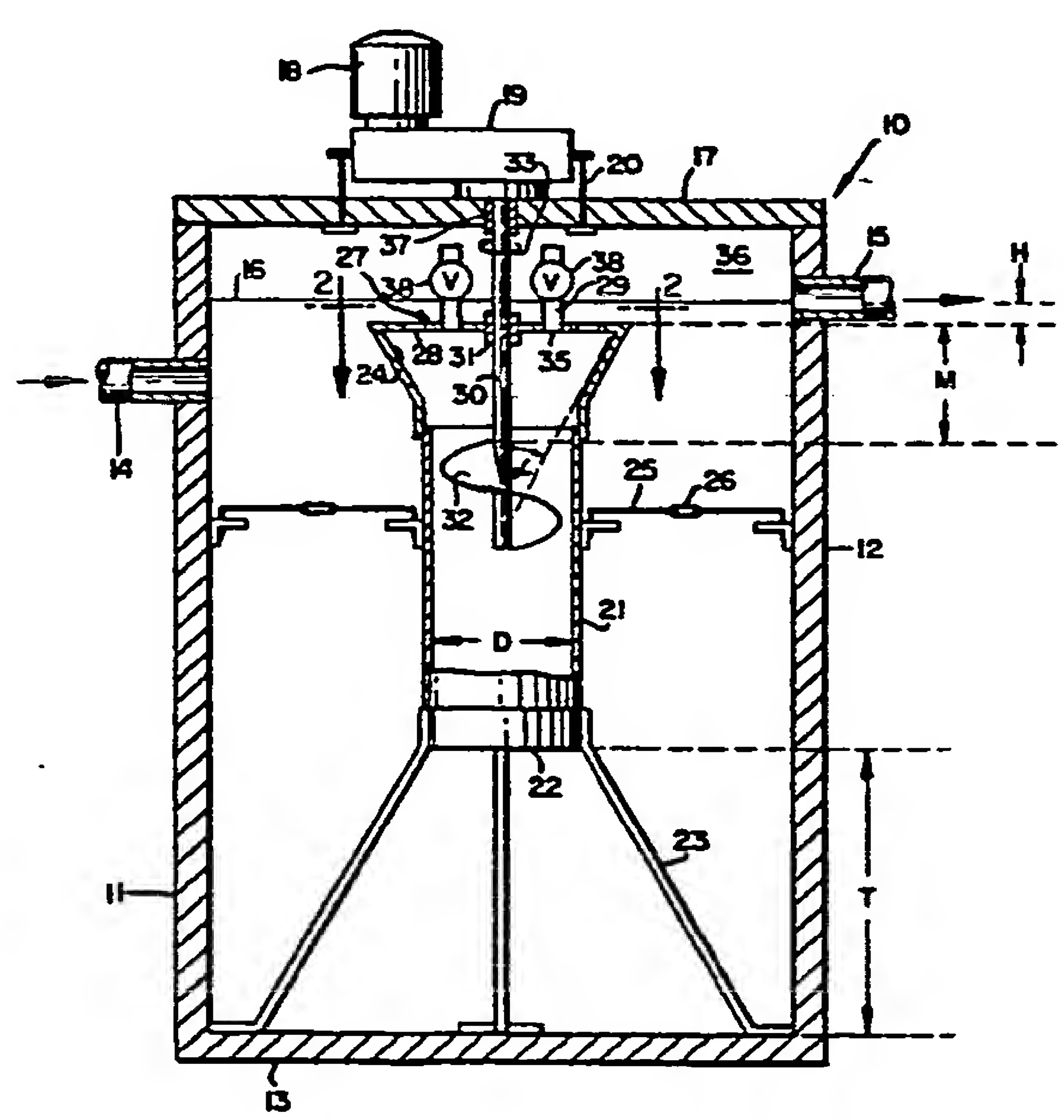
(54) **Apparatus for contacting liquid with a gas.**

(57) Apparatus for contacting liquid, in a tank (10) containing a body of same, with a gas. A generally tubular draft member (21) containing an axial downpumping impeller (32) is oriented in the tank with its central axis aligned vertically. Liquid flow restriction means (27) are positioned proximate the draft member liquid inlet (28) above the impeller and restricting cross-sectional liquid flow area of the liquid inlet to from 0.50 to 1.10 times cross-sectional area of the draft member. Gas flow passage means (29, 35, 38) are provided having an inlet opening exposed to a source of gas and an outlet positioned proximate to the liquid flow restriction means in liquid flowing to the axial pumping impeller means, whereby liquid flowing through the liquid flow restriction means under action of the axial pumping impeller is mixed with gas from the gas flow passage means to effect gas-liquid contacting in the liquid pumped by the axial pumping impeller.



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BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to apparatus for contacting liquid, in a tank containing a body of same, with a gas.

Description of the Prior Art

In the field of activated sludge sewage treatment, an aeration device must satisfy two basic requirements: (1) the aeration device must transfer sufficient oxygen into the mixed liquor to support biological activity and (2) the aeration device must satisfactorily mix the contents of the aeration vessel to avoid sedimentation and thereby maintain the pollutants in contact with the biological population. Furthermore, these two objectives are preferably accomplished with a minimum expenditure of power.

The prior art has typically relied on three distinct types of aeration apparatus to satisfy the requirements for activated sludge sewage treatment: submerged porous diffusers, submerged turbines and surface aeration devices.

The submerged porous diffuser represents the simplest aerator design. In the operation of this device, an aeration gas, typically air, is compressed and forced through the apertures of a stationary porous medium located at the bottom of a deep vessel containing sewage to be treated. As the gas emerges through the apertures of the porous medium, small bubbles of gas are formed.

The size of each bubble depends on various factors such as the size of the apertures, the gas flow rate, fluid viscosities and densities, and the interfacial surface tension. The gas bubbles formed are preferably as small as possible since the degree of mass transfer varies directly with the gas-liquid interfacial contacting area.

The porous diffuser has enjoyed widespread utilization in practice because of its simple design. It contains no moving parts and is relatively inexpensive. Nonetheless, the requirement of a gas compressor and associated maintenance requirements, clogging problems associated with small apertures of the porous medium, and the potential for insufficient mixing of the mixed liquor being treated, resulting in a dissolved oxygen gradient in the sewage, represent significant deficiencies of this type of device.

In submerged turbine aeration systems, the aeration gas is compressed and fed to the bottom of a vessel beneath a rotating impeller. The impeller may be of various types, as for example a radially discharging flat blade turbine, which both mixes the contents of the sewage treatment tank and breaks the aeration gas into small bubbles. Such operation ensures that the contents of the aeration tank are thoroughly and intimately contacted with the aeration gas, and allows independent control of the power consumption of the aeration device and the gas flow rate. As a result, very high oxygen transfer rates are possible in practice. Such advantage, however, is offset economically and structurally by the

the mechanical complexity associated with the requirement of a long shaft for the impeller and submerged bearings as well as by the need for a separate gas compression and recirculation system.

Another type of commonly employed wastewater aeration apparatus is the so-called surface aerator. In operation, the surface aerator is designed to draw liquid upwardly from the wastewater treatment vessel and pump it radially outwardly. In such operation, coarse droplets or sheets of liquid are thrown outwardly and gas is transferred into the liquid during the free flight thereof. Additional gas transfer is accomplished through entrainment of gas caused by impingement of the outwardly thrown liquid onto the free liquid surface of the body of liquid contained in the tank. Bulk mixing of the contents is promoted by the upward and outward circulation of liquid.

Surface aerators typically have the highest efficiencies among commercially available aeration apparatus. Furthermore, since the operation of surface aerators obviates the need for gas compression, and operation of the surface aerator at the liquid surface avoids the need for mechanical complexities associated with a long submerged shaft and submerged bearings, surface aeration devices have been widely used in practice. It is well known, however, that the highest efficiency values are obtained at low rotational speeds for the surface aeration device. Since commercially available drive motors typically operate at high rotational speeds, efficient operation requires the use of a complex gear reduction unit. The need for such gear reduction unit

substantially increases both the capital and operating costs of the aeration system. In addition, operation in deep tanks is not possible unless rotating impeller means are disposed in the lower portion of the tank to augment mixing of the tank contents; such modification reduces the efficiency of the entire apparatus as well as increasing the mechanical complexity thereof.

In light of the foregoing, it would be advantageous to provide an aeration device which would combine the advantages of the submerged aeration apparatus, as well as the advantages of the surface aerator, while avoiding their intrinsic deficiencies.

Accordingly, it is an object of the present invention to provide a submerged aeration system that avoids the need for gas compression while providing a high degree of gas-liquid contacting.

It is another object of this invention to provide a downwardly pumping submerged aeration system that operates proximate to the normal liquid surface of liquid in the aeration tank, thereby avoiding the power penalty associated with gas-liquid contacting under a large hydrostatic head of liquid.

It is a still further object of this invention to provide such a gas-liquid contacting system which operates by gas aspiration.

SUMMARY OF THE INVENTION

This invention relates to apparatus for contacting liquid, in a tank containing a body of same, with a gas.

The apparatus of this invention includes a generally tubular draft member oriented with its central axis aligned vertically and positioned in the tank with its upper end proximate to but beneath normal liquid level in the tank to form a submerged liquid inlet, and with its lower end vertically spaced from the bottom of the tank to form a submerged liquid outlet.

A rotatable axial pumping impeller is employed having a diameter which is smaller than but closely proximate to the diameter of the draft member. The rotatable impeller is positioned in the draft member between the inlet and the outlet thereof for axial down-flow pumping of liquid through the draft member and inducement of circulation of liquid discharged from the draft member liquid outlet through the body of liquid in the tank to the draft member liquid inlet.

Means are provided for rotating the impeller.

Liquid flow restriction means are positioned proximate the draft member liquid inlet above the impeller and restricting cross-sectional liquid flow area of the liquid inlet from 0.50 to 1.10 times cross-sectional area of the draft member.

The apparatus includes gas flow passage means having an inlet opening exposed to a source of gas and and outlet positioned proximate to the liquid flow restriction means in liquid flowing to the axial pumping impeller, whereby liquid flowing through the liquid flow restricted draft member inlet under action of the axial pumping impeller is mixed with gas from the gas flow passage means to effect gas-liquid contacting in the liquid pumped by the axial pumping impeller.

As used herein, the term "normal liquid level in the tank" means the liquid level in the tank when the gas-liquid contacting apparatus is not in operation. The term "cross-sectional liquid flow area" means the cross-sectional area of the draft member liquid inlet through which liquid entering the draft member is flowed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is sectional, elevational view of an apparatus for contacting liquid with a gas according to one embodiment of the present invention.

Figure 2 is a plan view of the Figure 1 apparatus, taken along line 2-2, showing the details of construction of liquid flow restriction means comprising a horizontally extending plate member.

Figure 3 is a sectional, elevational view of a gas-liquid contacting apparatus according to another embodiment of the invention.

Figure 4 is a plan view, taken along line 4-4 of Figure 3, showing the details of construction of liquid flow restriction means comprising a horizontally extending plate member.

Figure 5 is a sectional, elevational view of another embodiment of the invention.

Figure 6 is a plan view, taken along line 6-6 of Figure 5, showing the details of construction of the liquid flow restriction means of an embodiment wherein same is comprised by gas flow conduits positioned at the liquid inlet.

Figure 7 is a sectional elevational view of another embodiment of the invention.

Figure 8 is a plan view, taken along line 8-8 of Figure 7, showing the details of construction of the liquid inlet for the Figure 7 embodiment.

Figure 9 is a graph of normalized standard transfer efficiency as a function of the ratio of cross-sectional liquid flow area of the liquid inlet to cross-sectional area of the draft member, for an illustrative embodiment of the present invention.

Figure 10 is a sectional, elevational view of a draft member assembly according to another embodiment of the invention.

Figure 11 is a sectional, elevational view of a draft member assembly according to yet another embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, Figure 1 is a sectional, elevational view of gas-liquid contacting apparatus according to the present invention. The aeration tank 10 comprises sidewalls 11 and 12 and bottom member 13, filled with the liquid to be aerated to a level 16 via inlet conduit 14. Aerated treated liquid is withdrawn from the aeration tank 10 through conduit 15. At the top of the aeration tank is a bridge 17 upon which the motor drive means 18 and gear reduction unit 19 are supported. The motor and gear reduction unit are attached to the bridge 17 by connections 20. Shaft member 30 is connected to the gear reduction unit 19 by

bushing 37 in the bridge 17. At the lower end of the shaft member 30, a rotatable axial pumping impeller, helical screw impeller 32, is connected.

The shaft/rotatable impeller assembly is supported within the tank inside a generally tubular draft member 21. The generally tubular draft member is oriented with its central axis aligned vertically and positioned in the tank with its upper end proximate to but beneath normal liquid level in the tank to form a submerged liquid inlet, and with its lower end vertically spaced from the bottom of the tank to form a submerged liquid outlet 22. The draft member is supported in the tank by means of support struts 23 and a collar at its lower end and by the means of the side support members 25 at its intermediate portion. The tension on the side support means can be adjusted by adjusting means 26. The draft member 21 extends from just above the top of the helical impeller down into the tank near the vessel midpoint. The draft member can also be constructed to extend to a point closer to the bottom of the tank 10.

In this embodiment, the generally tubular draft member has a cylindrical main body portion with an inverted frustoconical inlet section 24. The enclosing walls of the inverted frustoconical inlet section form an angle α with the draft member central axis of from 10° to 40°, as for example 27°. The upper end of the draft member inlet section terminates below the liquid level 16 and preferably the submergence of the draft member liquid inlet H is from 0.10 to 1.25 times the diameter D

of the draft member, beneath the normal liquid level in the tnak. In practice, this submergence of the draft member liquid inlet may be from 3 inches to 3 feet beneath the normal liquid level in the tank. The inverted frustoconical inlet section preferably has a height of from 0.25 to 0.75 times the diameter D of the cylindrical main body portion of the draft member. As the inside angle of the frustoconical inlet section increases, the vertical height of the inlet section should commensurately decrease.

Attached to the top of the frustoconical inlet section 24 is a liquid flow restriction means 27 which is positioned proximate the draft member liquid inlet restricting cross-sectional liquid flow area of the liquid inlet, i.e., the "open area" of the draft member liquid inlet, measured in a horizontal plane at the point of restriction of the inlet, which is available for liquid flow into the draft member, from 0.50 to 1.10, and preferably from 0.70 to 1.0, times cross-sectional area ($\pi D^2/4$) of the draft member. The cross-sectional area of the draft member is the cross-sectional area of the main cylindrical body portion of the draft member, measured in a horizontal plane perpendicular to the central axis of the draft member. In this embodiment the liquid flow restriction means comprise a horizontally extending plate member positioned in the draft member proximate the liquid inlet thereof providing liquid passages for flowing liquid entering the draft member to the axial pumping impeller 32. The horizontally extending plate member is provided with a plurality of gas inlet openings 35 through

which gas conduits 29 extend forming the gas flow passage means. These gas flow conduits extend vertically with their upper ends positioned in the gas space 36 above the normal liquid surface and with their lower ends extending through and leak-tightly enclosing each of the gas flow openings in the plate member. Each conduit terminates at a lower end closely adjacent the plate member, so that during operation gas is drawn into liquid flowing downwardly through the liquid passages 28 under the action of the axial pumping impeller 32, to effect gas-liquid contacting. The upper ends of the gas conduits 29 are fitted with valves 38 for controlling the flow rate of gas therethrough. The liquid flow restriction means is also provided with a bushing or seal 31 for the shaft member 30.

In operation, the shaft member 30 is rotated in the direction shown by arrow 33 by means of motor drive means 18 and gear reduction unit 19 so as to pump liquid downwardly through the draft member 21. In this manner, liquid is drawn through the plurality of liquid flow openings 28 and, by rotating the impeller 32 at a sufficient rate, the flow of liquid through the liquid flow passages 28 induces a flow of gas through the conduits 29 by aspiration and effects gas entrainment in the downwardly flowing liquid. A gas/liquid mixture is thereby formed in the inlet section 24 and the resultant mixture is then pumped to the bottom of the tank by impeller 32 through the draft member 21. It has been found that devices of the type shown in Figure 1 exhibit optimum operating efficiencies similar to those achieved by surface aerator

devices at substantially higher rotational speeds than are optimally employed with surface aerators (i.e., 30-40 rpm) as for example on the order of above 150 rpm.

Figure 2 illustrates more clearly the details of construction of the plate member 27, as taken along line 2-2 of Figure 1. As shown, the plate member 27 provides a series of imperforate and perforate areas. The liquid flow passages 28 are provided in the form of six truncated pie-shaped openings and six small rectangular openings alternately spaced between one another. In the interior portion of the plate member symmetrically surrounding the shaft member 30 are six gas flow openings 35.

Figure 3 illustrates another embodiment of the invention. Shaft 130, provided with a helical screw impeller 132 is supported within a draft member 121. The inlet section of the draft member is outwardly and upwardly flared above a generally cylindrical main body portion of the draft member. The liquid flow restriction means comprises a horizontal plate member which is fitted into the inlet section. Preferably, the liquid flow restriction means is positioned less than 0.75 times the draft member diameter D below the liquid inlet upper end of the draft member. The plate member is provided with a plurality of liquid flow passages 128 and a bushing or seal 131 for the shaft member 130. Gas conduits 129 forming the gas flow passage means are also provided with their upper ends located in the gas space above the normal liquid surface and with their lower ends terminating just above the liquid flow passages 128 provided in plate member 127.

Figure 4, taken along line 4-4 of Figure 3, more clearly illustrates the design of the plate member 127 and its relationship to the gas conduits and inlet section. The liquid flow passages 18 are provided in the form of four truncated pie-shaped openings. The gas conduits 129 terminate within the space enclosed by these openings. In operation, shaft member 130 is rotated by means of a motor and gear reduction unit (not shown) so as to pump liquid downwardly through the draft member 121. In this manner, liquid is drawn through the plurality of liquid flow openings 128 into the draft member. By rotating the impeller 132 at a sufficient rate, the flow of liquid through the liquid flow passages 128 induces a flow of gas through the gas conduits 129 by aspiration. A gas/liquid mixture is thereby formed in the inlet 124 and the resultant mixture is then pumped to the bottom of the associated tank by impeller 132 through the draft member 121.

Figure 5 shows another embodiment of the present invention. Shaft 230 and impeller 232 are provided for downflow pumping of liquid through the draft member 221. In this embodiment, however, the gas conduit 229 forming the gas flow passage means also constitute the liquid flow restriction means 227.

As shown more clearly in Figure 6, which is a plan cross-sectional view taken along line 6-6 of Figure 5, the area obstructed by the gas conduits 229 serves to reduce the cross-sectional area available for liquid flow to the range required by the invention. In

operation, rotation of the shaft/impeller assembly forces liquid downwardly through the draft member. The rapid flow of liquid through the inlet section 224 and around the gas conduits causes gas to be aspirated through the conduits 229. The gas/liquid mixture formed in the inlet section is thereafter pumped by the impeller 232 throughout the tank.

In the embodiment shown in Figure 5, the impeller is an axial downpumping impeller of conventional marine propeller type. In the broad practice of the invention, the axial pumping impeller may suitably comprise a member selected from the group consisting of pitch blade turbines, marine propellers and helical screw impellers.

Another embodiment of the invention is shown in Figures 7 and 8. As in the preceding embodiments, a shaft 330 and impeller 332 assembly is disposed in a draft member 321 for pumping the liquid downwardly therethrough. In this embodiment, the generally tubular draft member 321 is of cylindrical form over its entire vertical extent. An inverted frustoconical guide member 327 is disposed at the liquid inlet of the draft member. The frustoconical guide member is open at its upper end and has enclosing side and bottom walls with gas flow passage openings in the bottom wall of the guide member. The side walls are imperforate. The frustoconical guide member is positioned at the liquid inlet of the draft member 321 such that lateral clearance exists between the guide member side walls and the enclosing walls of the draft member, whereby the clearance forms a liquid flow

area between the guide member side walls and enclosing walls of the draft member.

In operation of the Figures 7 - 8 system liquid is pumped downwardly by the impeller 332. Liquid flowing into the inlet section 324 flows rapidly past the frusto-conical guide member and causes gas to be aspirated through the gas passages 329. The gas/liquid mixture thus formed in the inlet section is thereafter pumped into the tank by impeller 332. Preferably, the vertical spacing (Z in the Figure 7 drawing) between the draft member liquid inlet upper end and the bottom wall of the inverted frustoconical guide member is no greater than 0.75 times the diameter D of the draft member. When the frustoconical guide member is used in combination with a draft member having a cylindrical draft member liquid inlet, the cross-sectional area for liquid flow past the guide member (as the liquid flows downwardly into the draft member) progressively increases. As a result, maximum liquid flow velocity occurs at the inlet and thereafter progressively decreases to the liquid flow velocity existing in the main cylindrical body portion of the draft member. While such operation does not maximize gas aeration, it does minimize upward flow or bypassing of aspirated gas, since at all locations in the liquid flow stream above the region of gas aspiration the liquid flow velocity is greater than the liquid flow velocity in the region of gas aspiration. If one wishes instead to maximize gas aspiration, then one would outwardly flare the draft member inlet section at an angle greater than

the angle of the side wall of the frustoconical guide member. In this manner, the cross-sectional area for liquid flow past the frustoconical guide member progressively decreases below the draft member liquid inlet, so that maximum liquid flow velocity occurs in the region of gas aspiration, thereby maximizing the extent of gas aspiration.

According to the well-known venturi phenomenon, the flow of the fluid through a relatively abrupt constriction causes rapid acceleration of the flow and produces a sharp decrease in the fluid pressure across the constriction. In similar fashion, as fluid flows around an obstruction in the flow path, a drop in pressure will be observed at the donwstream side of the obstruction. The present invention is designed to take full and optimum advantage of this phenomenon for aerating a liquid.

According to the present invention, a gas flow passage means is provided which directly connects a supply source of gas with a low pressure regime of a constriction or obstruction provided in the form of the liquid flow restriction means. Flow is induced through the liquid flow restriction means by the axial pumping impeller. At the condition when the fluid flow velocity through the liquid flow restriction means creates a pressure drop proximate the restriction greater than the hydrostatic pressure due to the submersion of the gas flow passage means plus any frictional losses associated with gas flow therethrough, gas will be aspirated into the liquid, thereby forming a two-phase mixture of gas in liquid below the liquid flow

restriction means. This two-phase mixture is then pumped down through the draft member and into the bulk liquid contents of the aeration tank by the axial pumping impeller.

Rather than designing the liquid flow restriction means of the present invention to maximize the velocity change and thereby the pressure differential across the liquid flow restriction means, which accordingly will result in maximum gas aspiration. It has unexpectedly been found that optimum aeration performance occurs when the liquid flow restriction means are positioned proximate the draft member liquid inlet, restricting cross-sectional liquid flow area of the liquid inlet to from 0.50 to 1.10 times cross-sectional area of the draft member. Preferably, for reasons to be discussed hereinbelow, the ratio of the liquid flow area through the liquid flow restriction means to the draft member cross-sectional area should be between 0.7 and 1.0.

To induce aspiration at optimum power expenditures, the inlet to the draft member must be located proximate to but beneath the normal liquid level. If the liquid inlet of the draft member is submerged too deeply within the aeration tank, it has been found that an excessive power expenditure is required to achieve aspiration proximate the inlet. As a result, mass transfer efficiency of the contacting system tends to decrease. On the other hand, if the liquid inlet of the draft member is located too close to the normal liquid level, it has been found that regardless of the power utilization level there will be

insufficient liquid flow through the liquid inlet to induce and support adequate aspiration, i.e., the system will be starved for liquid. As a result, the draft member liquid inlet should preferably be located between about 0.10 and 1.25 times the draft member diameter beneath the normal liquid level in the aeration tank. The lower end of this range, i.e., from 0.1 to 0.75, tends to be more properly applied to large draft member diameters, i.e., greater than 3 feet, while the upper end of the range, i.e., from 0.5 to 1.25 tends to be more properly applied to small draft member diameters, i.e., less than 3 feet. In most instances, submergences between 3 inches and 3 feet below the normal liquid level may advantageously be employed.

At its lower end, the draft member liquid outlet should preferably be spaced a substantial distance above the bottom of the tank in which the draft member is disposed. Although the prior art has taught that in order to provide adequate mixing, draft member outlets should be positioned closely adjacent the floor of the aeration tank, it has been found that at optimum operating conditions for the present invention such close spacings are not required in order to ensure adequate mixing. In fact, it has been found that extension of the draft member too near the tank bottom adversely rather than beneficially effects overall aeration efficiency. The reason for this effect is believed to be that the pressure field created within the draft member by the hydraulic interference between the high velocity fluid flow existing the draft

member and the floor of the aeration tank exerts a deterimental influence on the pumping capabilities of the axial pumping impeller. This effect in turn reduces the gas aspiration capability of the overall system. As a result, the draft member liquid outlet is preferably Spaced at least two times the draft member diameter from the bottom of the aeration tank. Based on the same reason, the liquid outlet of the draft member is preferably free of constriction and not tapered in any manner whatsoever.

In the general practice of the invention, the impeller can be located anywhere in the draft member between the liquid inlet and liquid outlet thereof, although in some designs adequate performance requires careful positioning of the impeller. If possible in the particular application, the impeller means is located at least 0.35 times and preferably at least 0.5 times the draft member diameter below the flow restricted liquid inlet upper end (dimension M in Figure 1 and Figure 5).

The present invention contemplates a variety of designs which satisfy the constraints of the liquid flow restriction means. For example, the liquid inlet may be provided with an appropriately apertured horizontal plate member as shown in Figures 2 and 4. Alternatively, the gas flow passage means themselves, provided in the form of tubular conduits, may be used to suitably restrict the liquid flow area to the inlet, as shown in the Figure 5 - 6 embodiment. The design of the liquid flow restriction means is critical insofar as it influences the design of the liquid flow passages. To satisfactorily utilize the

pumping capabilities of the impeller to produce aspiration, liquid flow to the impeller must be unencumbered. In other words, the liquid flow restriction means is designed to offer a minimum resistance to liquid flow. In this manner, the frictional losses incurred in converting pumping energy to fluid flow kinetic energy are minimized.

The physical design relationship between the gas flow passage means and the liquid flow restriction means, however, does not appear to be critical. It is only necessary to position the gas flow passage means proximate to the liquid flow restriction means, as required in the broad practice of the invention. Preferably, the orientation is such that the liquid flowing through the liquid flow restriction means flows generally parallel to the direction of gas aspiration. In this manner, the aspiration level at a given power expenditure is maximized.

In the broad practice of the present invention, both the liquid flow restriction means and the gas flow passage means are located proximate the liquid inlet. In preferred practice, the flow restriction means are positioned less than about 0.75 times the draft member diameter below the liquid inlet upper end. Inasmuch as aspiration does not occur until the flow of liquid through the liquid flow restriction means creates a pressure drop proximate the restriction greater than the hydrostatic pressure existing at the discharge end of the gas flow passage means plus any frictional losses associated with gas flow through the gas flow passage means, the greater the submergence of the flow restriction means and the gas

flow passage means, the more pumping is required to achieve aspiration. Design conditions yielding the highest aspiration level at the lowest power expenditure are preferred.

As stated hereinabove, it has been found that optimum performance in the practice of the present invention is realized when the ratio of cross-sectional liquid flow area to cross-sectional area of the draft member is between 0.50 and 1.10. Referring now to Figure 9, there is illustrated the experimentally observed functional relationship between operating efficiency (normalized standard transfer efficiency) and the ratio of cross-sectional liquid flow area to cross-sectional area of the draft member. The data illustrated in Figure 9 were obtained in a 30 foot test basin using an aerator configuration of the general type shown in Figure 1 herein. This system included a 48 inch diameter draft member main cylindrical portion with a 36 inch high, 30° inside angle conical inlet. The liquid inlet upper end of the draft member was positioned 17.1 feet above the floor of the aeration tank. A helical screw impeller was used as the axial pumping impeller means and data were obtained at various inlet submergences.

As shown in Figure 9, the data illustrates a maximum in the range between 0.8 and 0.9 for the ratio of cross-sectional liquid flow area to cross-sectional area of the draft member. Preferably, the present invention is practiced with the cross-sectional liquid flow area of the liquid inlet being from 0.70 to 1.0 times the cross-sectional

area of the draft member, because, as reflected in the data of Figure 9, the apparatus operates within at least 75% of the peak standard transfer efficiency value in this area ratio range. At the high end of the area ratio ordinate of Figure 9, the graph indicates that there is a rather rapid degeneration in operating efficiency with increasing area ratio values, due to the increasing difficulty of achieving aspiration at progressively higher area ratio values. At the low end of the area ratio ordinate of Figure 9, the graph indicates a gradual degeneration in operating standard transfer efficiency. This degeneration is believed to be due to the combination of two interrelated effects. On the one hand, at increasingly lower area ratios, the quantity of gas aspirated relative to the quantity of liquid pumped increases. Since impeller means are less efficient in pumping gas-in-liquid mixtures as opposed to a single phase liquid, more power is required for fluid pumping at progressively lower values of the area ratio ordinate. Secondly, the higher degree of liquid flow restriction at the lower area ratio values results in a higher pressure drop accompanying the flow, so that additional power must be supplied by the impeller means to overcome such increased pressure drop.

Figure 10 shows a draft member assembly according to another embodiment of the invention. The draft member 521 is of generally tubular shape and is oriented in a liquid treatment tank of the type shown in Figure 1 with the central axis of the draft member aligned vertically

and with the draft member positioned in the tank with its upper end proximate to but beneath normal liquid level in the tank to form a submerged liquid inlet and with the lower end of the draft member vertically spaced from the bottom of the tank to form a submerged liquid outlet. Rotatable impeller 532 having a diameter which is smaller than but closely proximate to the inner diameter of the draft member is positioned in the draft member between the liquid inlet and outlet thereof. The impeller 532 is mounted on shaft 530 which is joined to suitable drive means (not shown) for rotatation of the shaft and impeller at suitable speed for axial downflow pumping of liquid through the draft member and inducment of circulation of liquid in the tank in which the draft member is disposed. Gas flow passage means 501 comprising a ring sparger is disposed in the inlet section of the draft member as shown, above the axial flow impeller. The ring sparger provides gas flow passage means in the form of gas discharge openings on the underside of the ring which communicate with a gas flow feed conduit joined to a source of super-atmospheric pressure gas for positive pressure injection of gas into the liquid flowing through the draft member liquid inlet toward the axial flow pumping impeller 532. In this embodiment, the ring sparger occludes a portion of the cross-sectional area of the draft member liquid inlet section and thus constitutes a liquid flow restriction means in the draft member liquid inlet, as required by the present invention.

Figure 11, is a sectional, elevational view of the draft member assembly according to yet another

embodiment of the invention. Disposed in the draft member 621 is a rotatable impeller 632 of pitched blade configuration to provide for axial downflow pumping of liquid through the draft member and inducement of circulation of liquid in the tank in which the draft member is disposed. Axial flow impeller 632 is mounted on rotatable shaft 630. Mounted at the upper portion of the shaft 630 is a ring sparger 601 having gas flow discharge openings on its underside communicating with a hollow passageway 602 in the upper portion of the shaft. The hollow passage 602 in shaft 630 is joined at its inlet end to a source of superatmospheric pressure gas. In operation of the Figure 11 system, gas is supplied from the aforementioned gas source through passageway 602 to the gas discharge openings on the underside of ring sparger 601, for injection of gas from the ring sparger into the liquid downwardly pumped under the action of the axial downflow pumping impeller 632.

In the systems of Figures 10 and 11, described above, a gas source supplies gas at superatmospheric pressure for positive pressure injection thereof into the liquid downwardly flowing through the draft member. In the previously described embodiments of Figures 1 - 8, gas is supplied to the contacting system at substantially atmospheric pressure, whereby liquid flowing through the flow restriction means under action of the axial pumping impeller causes gas to be aspirated through the gas flow passage means into the liquid flowing to the axial pumping impeller. It will be recognized, however, that the systems

of Figures 1 - 8 may also be suitably modified to provide for positive pressure injection of gas from a source providing same at superatmospheric pressure, and that the Figures 10 and 11 systems may be adapted to gas aspiration operation.

In a preferred practice of the invention, it is desirable that the relationship between the cross-sectional liquid flow area of the draft member liquid inlet, A_1, the cross-sectional area of the main cylindrical body portion of the draft member, A_2, and the total cross-sectional area of the draft member liquid inlet as measured in a horizontal plane at the point of liquid flow restriction of the inlet, A_3, is governed by the following equation:

$$0.5 \leq \frac{A_1}{A_2} \leq 2.31 \times (A_3/A_2)^{0.75} - 1.4 \times (A_3/A_2)$$

By this equation, one is able to determine the cross-sectional liquid flow area of the draft member liquid inlet, A_1, for a given draft member configuration, i.e., given known values A_2 and A_3. For example, for a draft member configuration of the type shown in Figures 1 - 2, characterized by a cross-sectional area of the main cylindrical body portion (A_2) of 12.6 ft^2, based on a main cylindrical body portion diameter of 4 feet, and a total cross-sectional area of the draft member liquid inlet (A_3) as measured in a horizontal plane at the point of liquid flow restriction of the inlet of 43.7 ft^2, a value for the cross-sectional liquid flow area of the draft member inlet (A_1) of between 6.3 ft^2 and 12.8 ft^2

for example 10.7 ft^2 is calculated. Looking now at Figure 2, this cross-sectional liquid inlet flow area requirement (10.7 ft^2) could suitably be accommodated by the six larger liquid flow openings 28 each being about 1.6 ft^2 in area and the six smaller liquid flow openings 28 each being about 0.2 ft^2 in area.

In connection with the foregoing, it has been found that the gas-liquid contacting systems of the type shown in Figures 10 and 11 may not, in some applications, require liquid flow restriction means restricting cross-sectional liquid flow area of the draft member liquid inlet to from 0.5 to 1.1 times the cross-sectional area of the draft member, as otherwise necessary in the general practice of the present invention.

Although preferred embodiments of the invention have been described in detail, it will be appreciated that other embodiments are contemplated only with modifications of the disclosed features, as being within the scope of the invention.

WHAT IS CLAIMED IS:

1. Apparatus for contacting liquid, in a tank containing a body of same, with a gas, comprising:

(a) a generally tubular draft member oriented with its central axis aligned vertically and positioned in said tank with its upper end proximate to but beneath normal liquid level in said tank to form a submerged liquid inlet, and with its lower end vertically spaced from the bottom of said tank to form a submerged liquid outlet;

(b) a rotatable impeller having a diameter which is smaller than but closely proximate to the diameter of said draft member, positioned in said draft member between said inlet and said outlet thereof for axial down-flow pumping of liquid through said draft member and inducement of circulation of liquid discharged from said draft member liquid outlet through said body of liquid in said tank to said draft member liquid inlet;

(c) means for rotating said impeller;

(d) liquid flow restriction means positioned proximate said draft member liquid inlet above said impeller and restricting cross-sectional liquid flow area of said liquid inlet to from 0.50 to 1.10 times cross-sectional area of said draft member;

(e) gas flow passage means having an inlet exposed to a source of gas and an outlet positioned proximate to said liquid flow restriction means in liquid flowing to said axial pumping impeller, whereby liquid flowing through said liquid flow restricted draft member inlet under action of said axial pumping impeller is mixed

with a gas from said gas flow passage means to effect gas-liquid contacting in the liquid pumped by said axial pumping impeller.

2. Apparatus according to claim 1 wherein said generally tubular draft member has a cylindrical main body portion with an inverted frustoconical inlet section.

3. Apparatus according to claim 2 wherein said inverted frustoconical inlet section has a height of from 0.25 to 0.75 times the diameter of said cylindrical main body portion.

4. Apparatus according to claim 2 wherein enclosing walls of said inverted frustoconical inlet section form an angle with the draft member central axis of from 10° to 40°.

5. Apparatus according to claim 1 wherein said flow restriction means comprise a horizontally extending plate member, positioned in said draft member proximate the liquid inlet thereof, providing at least one liquid passage for flow of liquid entering said draft member to said axial pumping impeller.

6. Apparatus according to claim 5 wherein said gas flow passage means comprise at least one gas flow opening in said plate member, each gas flow opening surrounded by imperforate portions of said plate member, and separate gas flow conduits extending through and leak-tightly enclosing each of said gas flow openings in said plate member, said conduits each terminating at a lower end closely adjacent said plate member and joined at an opposite end to said source of gas, whereby gas is

drawn into liquid flowing downwardly through said plate member liquid passage(s) under the action of said axial pumping impeller, to effect gas-liquid contacting.

7. Apparatus according to claim 5 wherein said gas flow passage means comprise a gas flow conduit extending toward and terminating at each said plate member liquid passage and joined at an opposite end to said source of gas, said gas flow conduit being of smaller cross-section than said liquid passage, whereby during operating gas is drawn from said gas flow conduit into liquid flowing downwardly through said plate member liquid passage(s) under the action of said axial pumping impeller means to effect gas-liquid contacting.

8. Apparatus according to claim 1 wherein said generally tubular draft member has a cylindrical main body portion with an outwardly and upwardly flared conical inlet section forming said draft member inlet at its upper end.

9. Apparatus according to claim 1 wherein said axial pumping impeller comprises a member selected from the group consisting of pitched blade turbines, marine propellers and helical screw impellers.

10. Apparatus according to claim 1 wherein the submergence of said draft member liquid inlet is from 0.10 to 1.25 times the diameter of said draft member beneath said normal liquid level in said tank.

11. Apparatus according to claim 10 wherein said submergence of said draft member liquid inlet is from 3 inches to 3 feet beneath said normal liquid level in said tank.

12. Apparatus according to claim 1 wherein the cross-sectional liquid flow area of said liquid inlet is from 0.7 to 1.0 times the cross-sectional area of said draft member.

13. Apparatus according to claim 1 wherein the vertical spacing between said draft member liquid oulet and the bottom of said tank is at least two times the diameter of said draft member.

14. Apparatus according to claim 1 wherein the vertical spacing between said draft member liquid inlet upper end and said axial pumping impeller is at least 0.5 times the diameter of said draft member.

15. Apparatus according to claim 1 wherein said liquid flow restriction means comprise said gas flow passage means.

16. Apparatus according to claim 15 wherein said gas flow passage means comprise gas flow conduits, said conduits extending toward and terminating proximate to said draft member liquid inlet and joined at opposite ends to said source of gas.

17. Apparatus according to claim 16 wherein the vertical spacing between said draft member liquid inlet and said axial pumping impeller means is at least 0.35 times the diameter of said draft member.

18. Apparatus according to claim 1 wherein said generally tubular draft member is of cylindrical form over its entire vertical extent, with an inverted frusto-conical guide member disposed at the liquid inlet of said draft member, said inverted frustoconical guide member being (1) open at its upper end and having enclosing side

and bottom walls with gas flow passage openings in said bottom wall thereof, with said side walls being imperforate, and (2) positioned at said liquid inlet of said draft member such that lateral clearance exists between said guide member side walls and enclosing walls of said draft member, whereby said clearance forms a liquid flow area between said guide member side walls and enclosing walls of said draft member.

19. Apparatus according to claim 18 wherein the vertical spacing between said draft member liquid inlet upper end and said bottom wall of said inverted frusto-conical guide member is no greater than 0.75 times the diameter of said draft member.

20. Apparatus according to claim 1 wherein said source of gas supplies gas at substantially atmospheric pressure, whereby liquid flowing through said flow restriction means under action of said axial pumping impeller causes gas to be aspirated through said gas flow passage means into the liquid flowing to said axial pumping impeller.

21. Apparatus according to claim 1 wherein said means for rotating said impeller effect rotation at a speed of at least 150 rpm.

22. Apparatus according to claim 1 wherein the relationship between the cross-sectional liquid flow area of the draft member liquid inlet, A_1, the cross-sectional area of the main cylindrical body portion of the draft member, A_2, and the total cross-sectional area of the draft member liquid inlet as measured in a horizontal plane

at the point of liquid flow restriction of the inlet, A_3. is governed by the following equation:

$$0.5 \leq A_1/A_2 \leq 2.31 \times (A_3/A_2)^{0.75} - 1.4 \times (A_3/A_2).$$

23. Apparatus for contacting liquid, in a tank containing a body of same, with a gas, comprising:

(a) a generally tubular draft member oriented with its central axis aligned vertically and positioned in said tank with its upper end proximate to but beneath normal liquid level in said tank to form a submerged liquid inlet, and with its lower end vertically spaced from the bottom of said tank to form a submerged liquid outlet;

(b) a rotatable impeller having a diameter which is smaller than but closely proximate to the diameter of said draft member, positioned in said draft member between said inlet and said outlet thereof for axial down-flow pumping of liquid through said draft member and inducement of circulation of liquid discharged from said draft member liquid outlet through said body of liquid in said tank to said draft member liquid inlet;

(c) means for rotating said impeller;

(d) gas flow passage means having an inlet exposed to a source of gas and an outlet positioned in liquid flowing to said axial pumping impeller, whereby liquid flowing through said draft member inlet under action of said axial pumping impeller is mixed with gas from said gas flow passage means to effect gas-liquid contacting in the liquid pumped by said axial pumping impeller.

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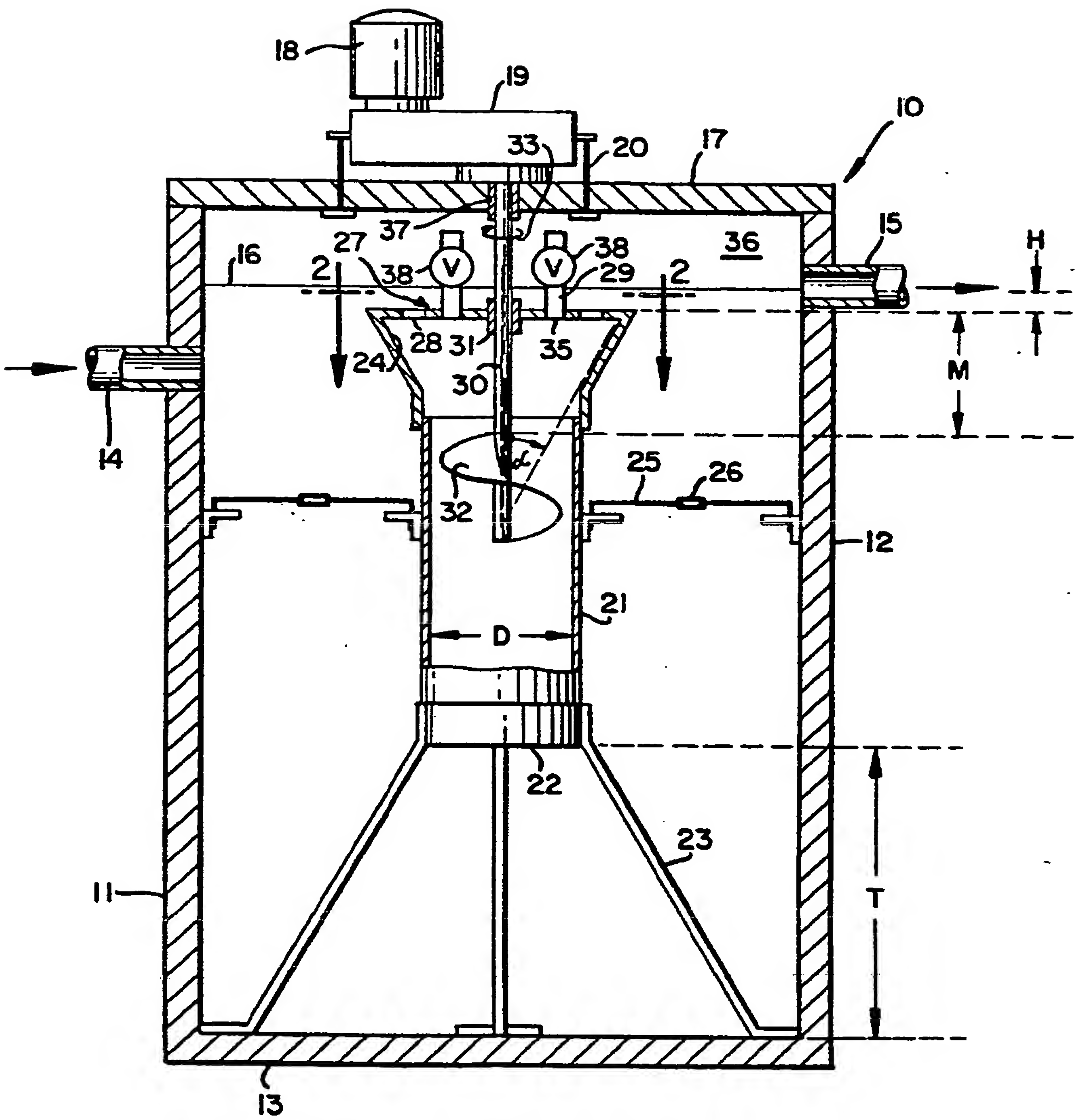
FIG. 1



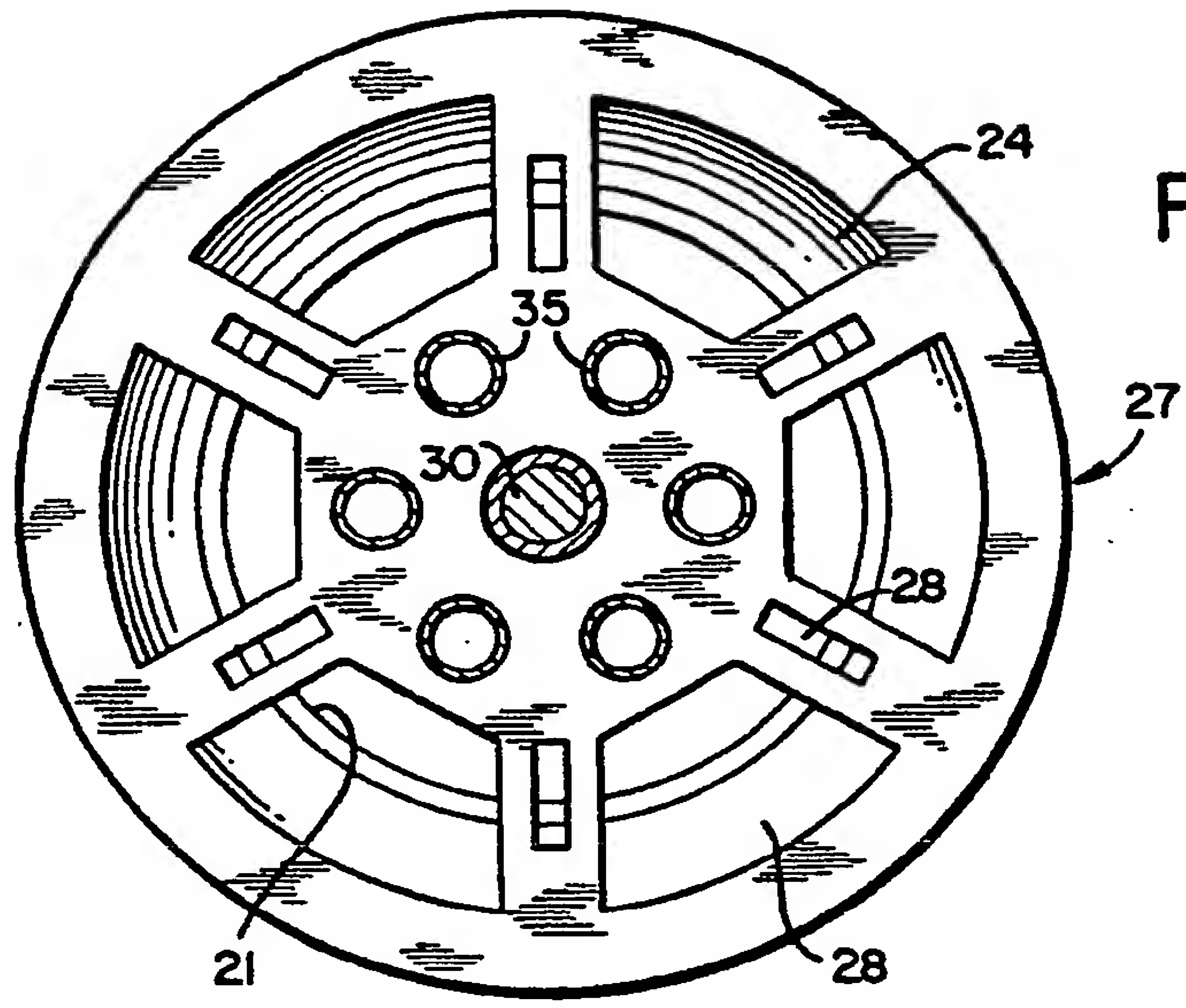


FIG. 2

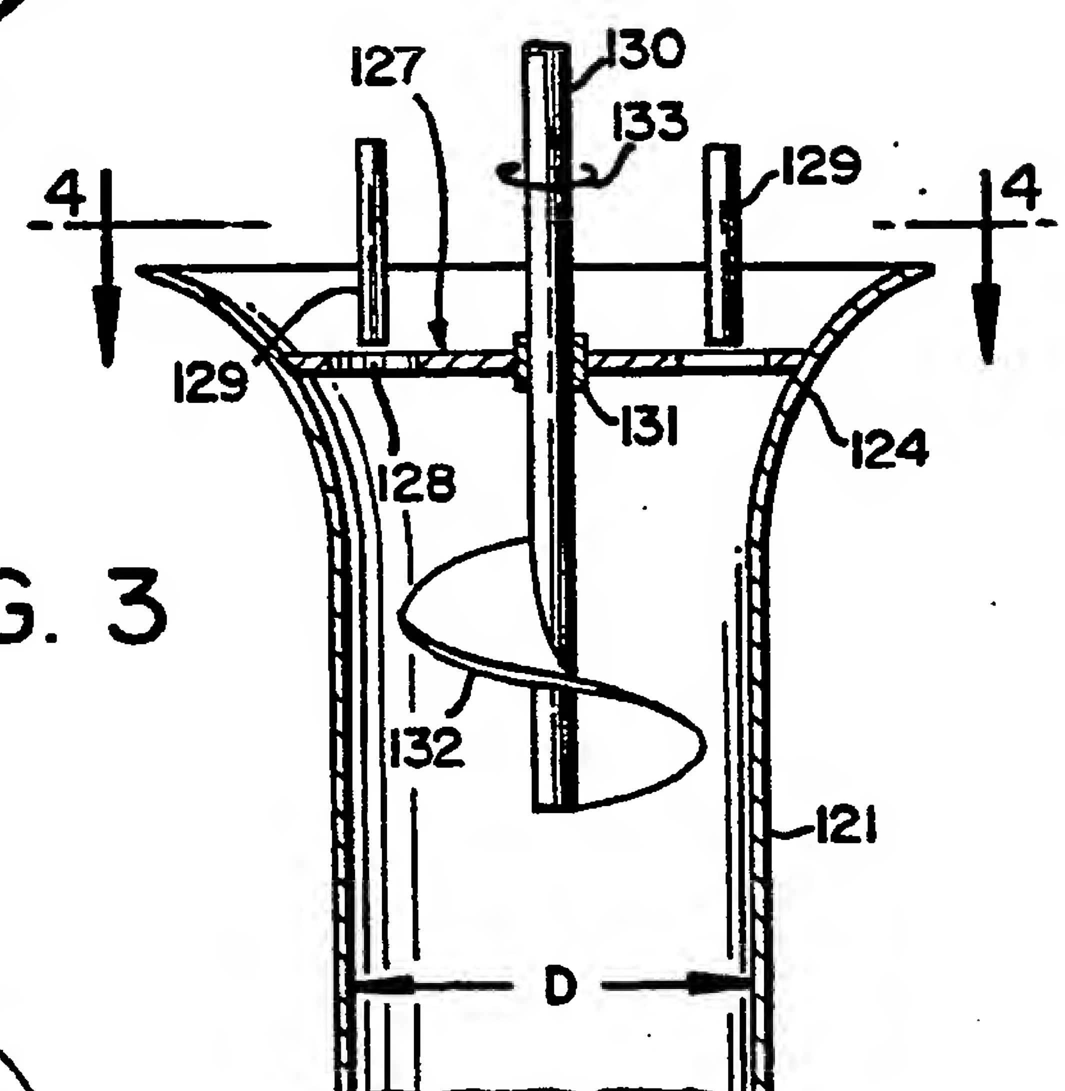


FIG. 3

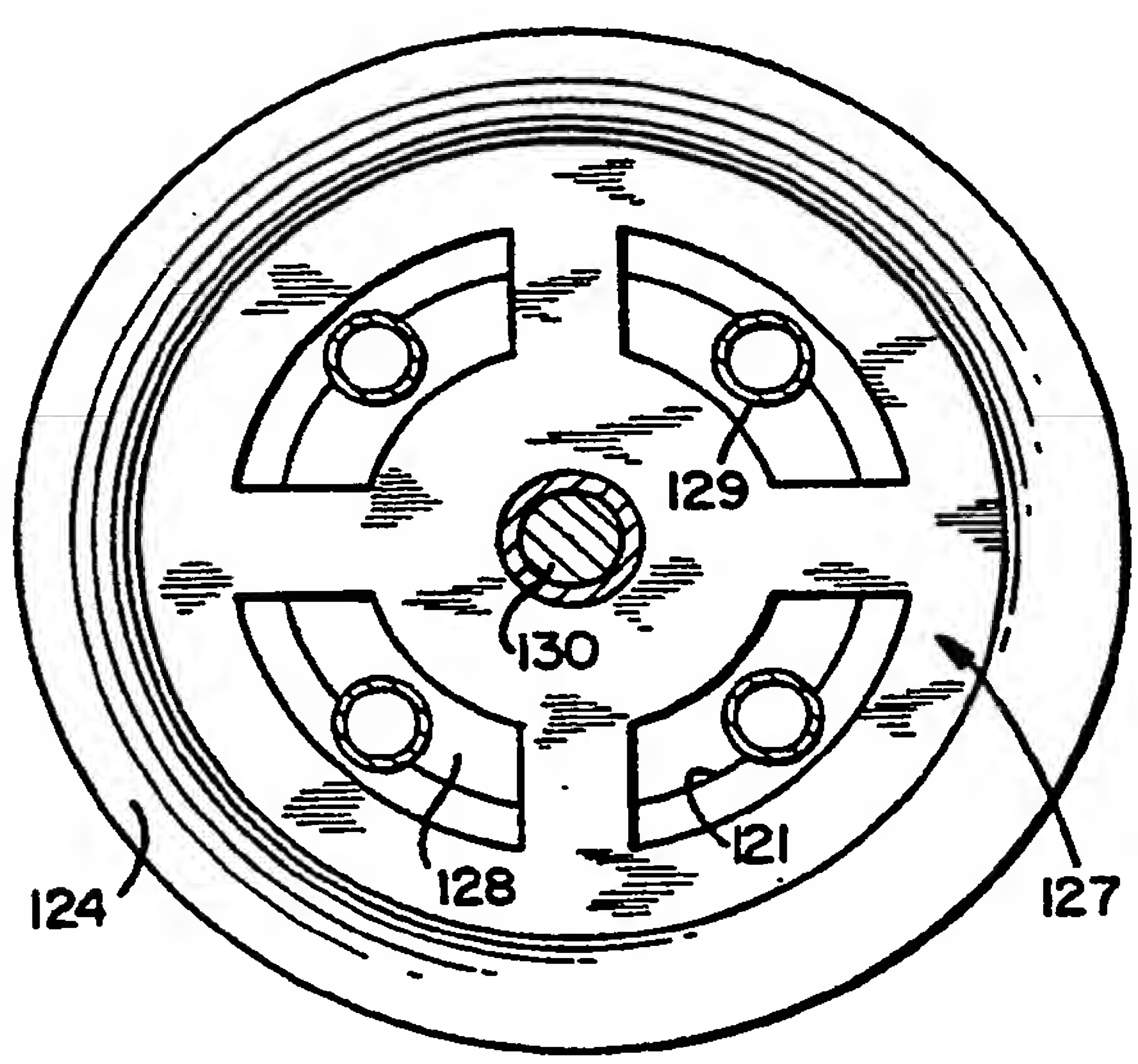


FIG. 4

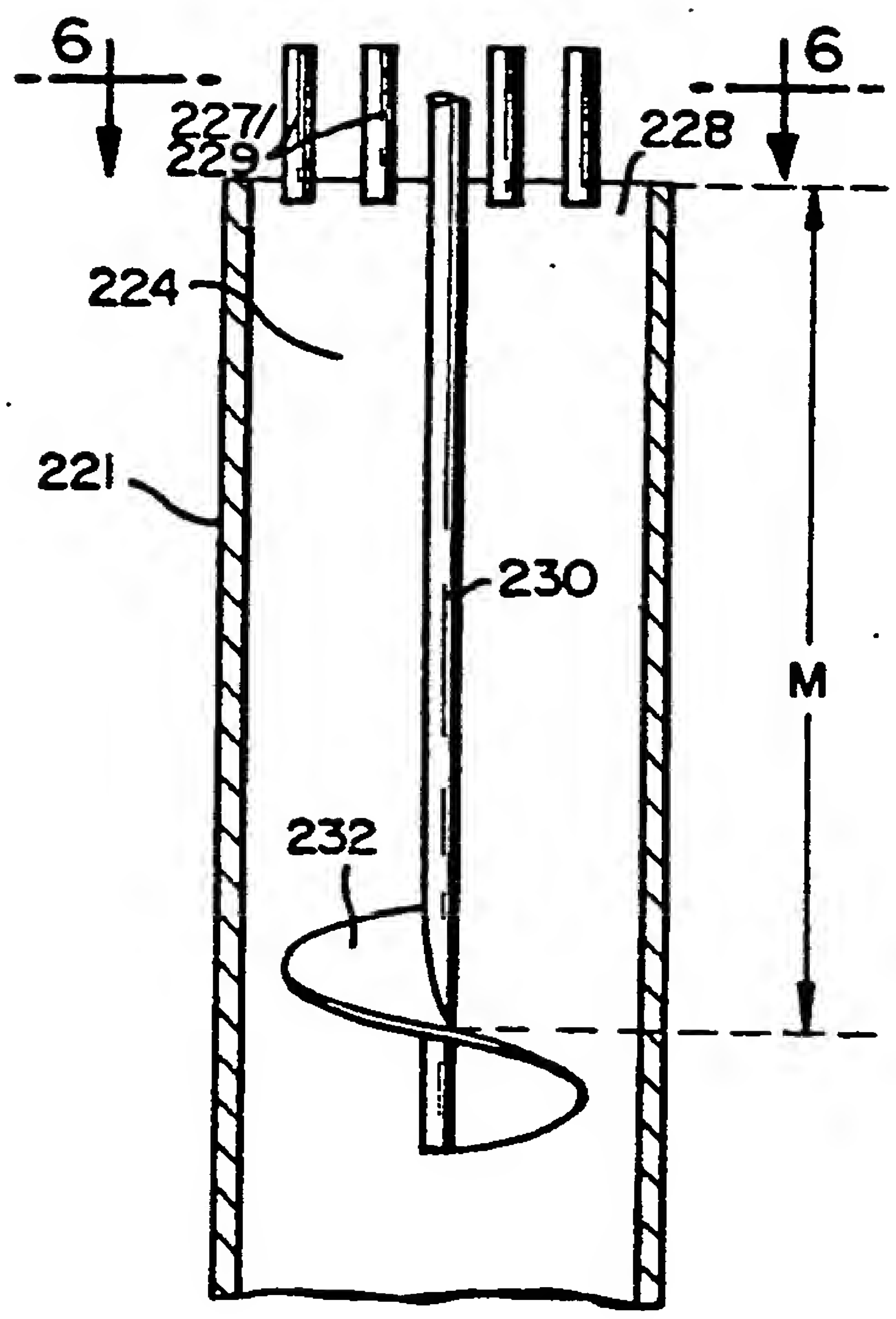


FIG. 5

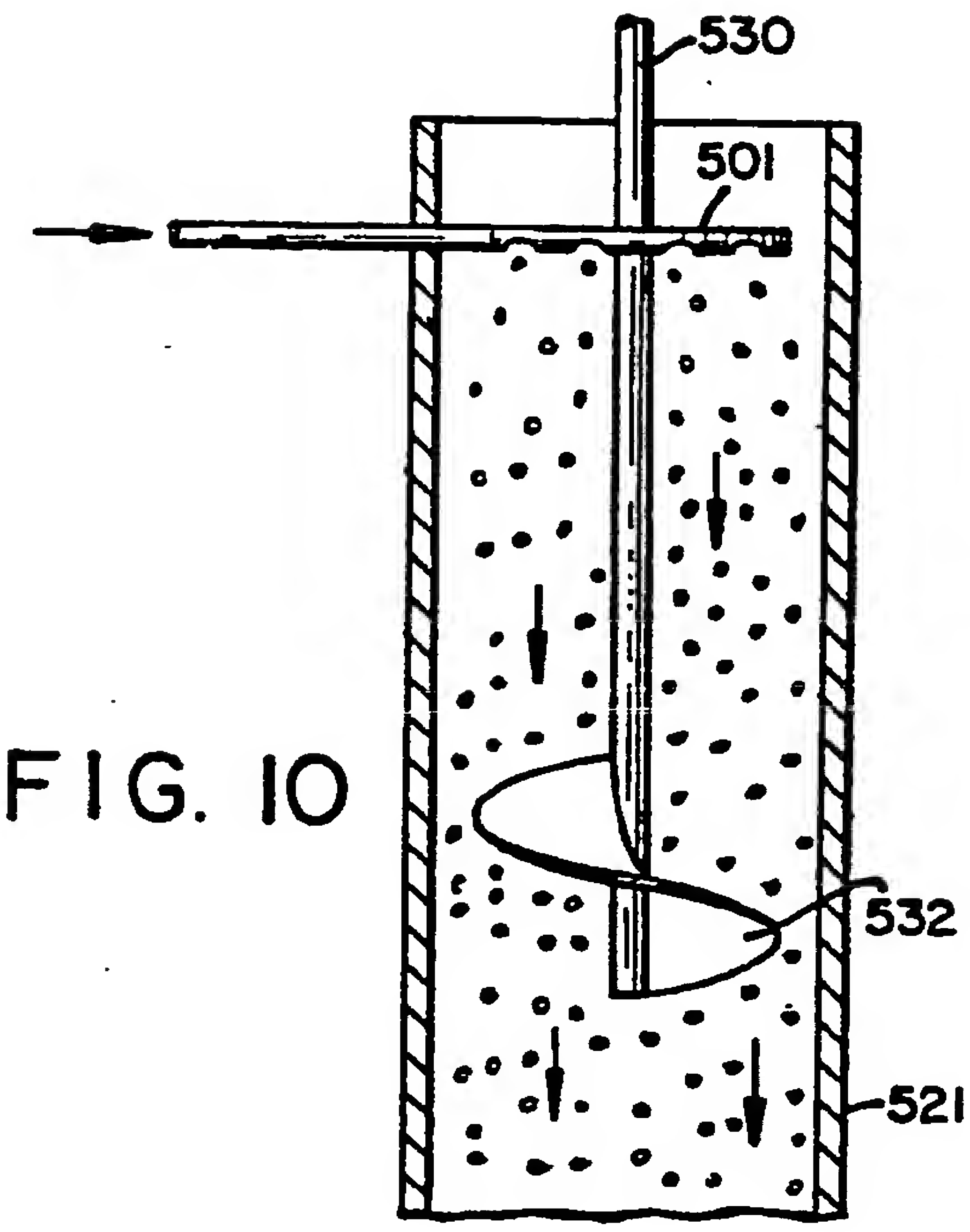


FIG. 10

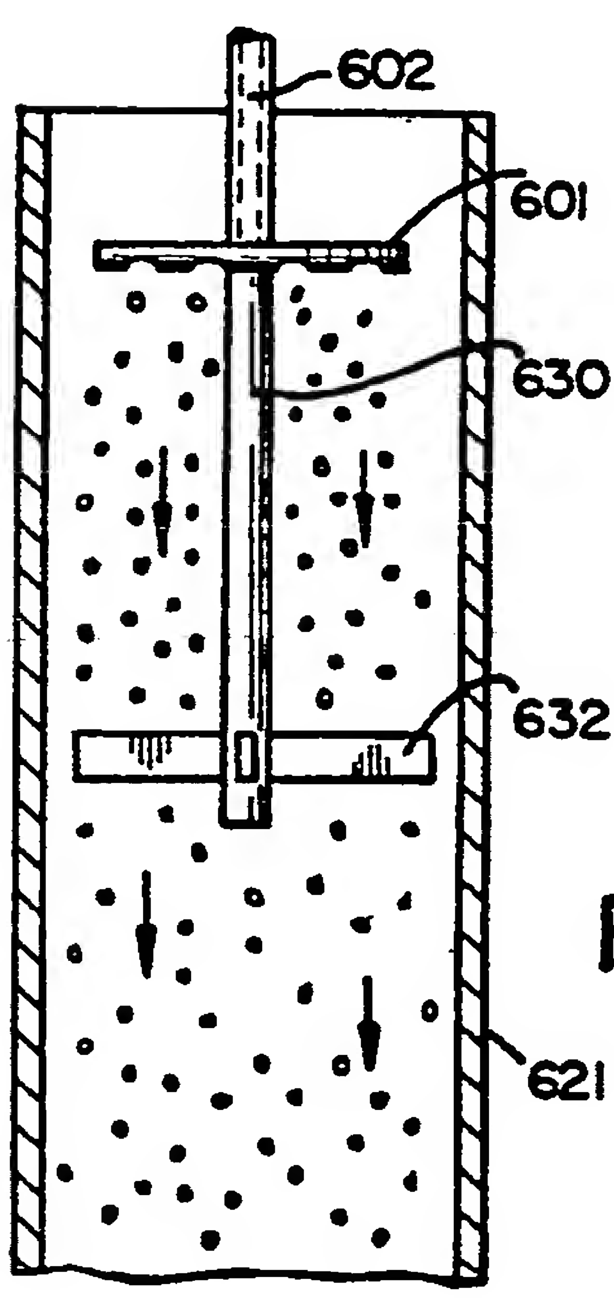


FIG. 11

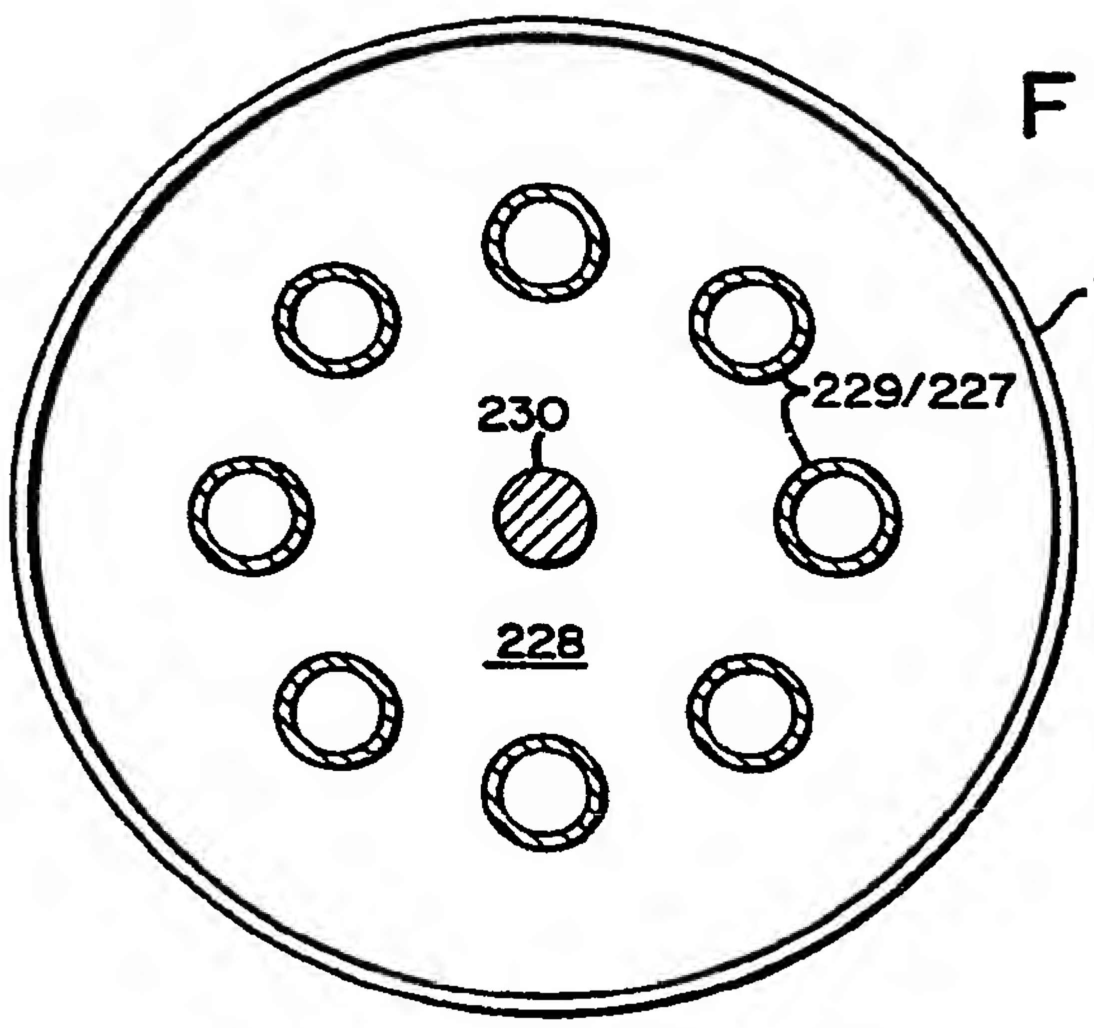


FIG. 6

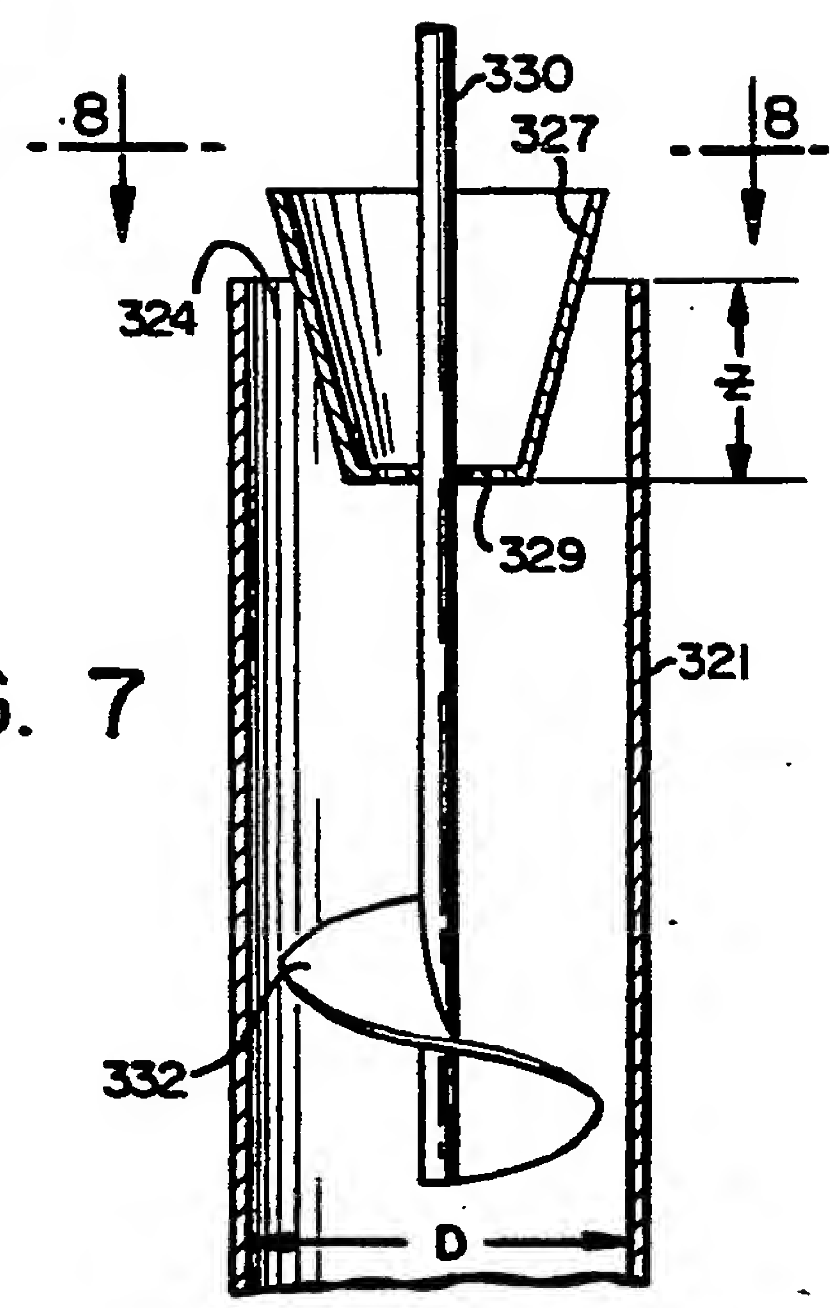


FIG. 7

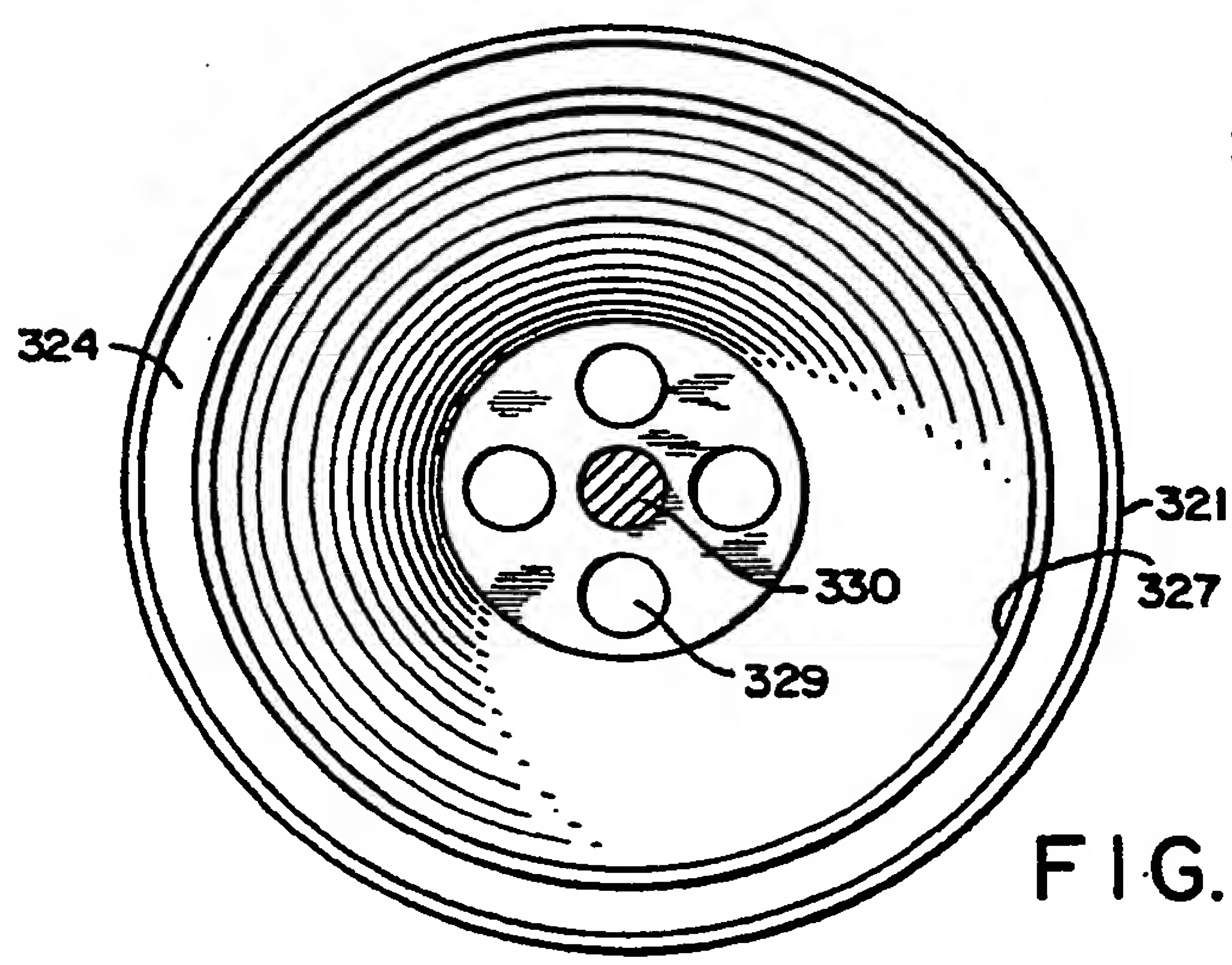


FIG. 8

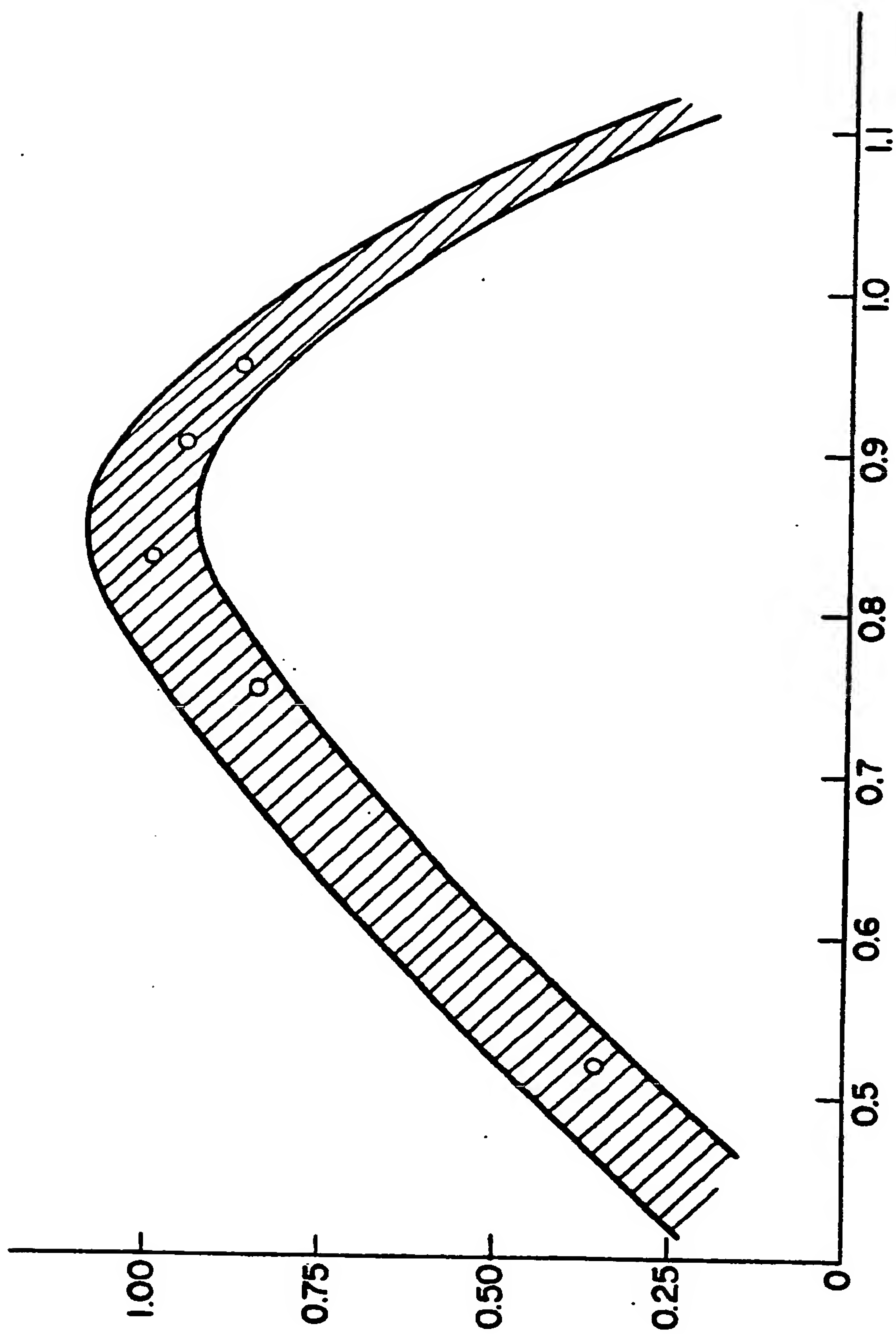


FIG. 9

European Patent Office

EUROPEAN SEARCH REPORT

0027911

Application number
EP 80 10 5914.8

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
	US - A - 4 017 565 (H. MÜLLER) * fig. *	2,8-10
	CH - A - 509 943 (J.R. KAELIN) * fig. 1, 2, position 37 *	1,2,5, 8-10 14,23
	CH - A - 563 801 (LINDE) * fig. 2 *	5,6,23
	DE - U - 7 222 305 (F. HAHNEWALD KG) * page 1, paragraph 3; page 3, paragraph 1 *	2
A	GB - A - 1 450 612 (AIRCO) * fig. 1 *	
A	GB - A - 1 495 902 (AIRCO) * fig. 1 *	

CLASSIFICATION OF THE APPLICATION (Int. Cl.³)

B 01 F 3/04
//B 01 F 7/24
C 02 F 3/14
C 12 M 1/04

TECHNICAL FIELDS SEARCHED (Int. Cl.³)

B 01 F 3/04
B 01 F 7/24
B 01 F 13/02
C 02 F 3/02
C 02 F 3/14
C 02 F 3/16
C 02 F 7/00
C 12 M 1/04
C 12 M 1/06

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
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O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	23-01-1981	KÜHN

EPO Form 1503.1 06.78